The Effect of Regionally Integrated Energy Systems on CO2 Emissions Reduction and Wind Integration: the Case of South East Europe

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9 authors, including:


Goran Krajacic
University of Zagreb


Natasa Markovska
Macedonian Academy of Sciences and Arts

Zihnija Hasovic
Sarajevo School of Science and Technology


Neven Duic
University of Zagreb

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THE EFFECT OF REGIONALLY INTEGRATED ENERGY SYSTEMS ON CO_2 EMISSIONS REDUCTION AND WIND INTEGRATION: THE CASE OF SOUTH EAST EUROPE

Boris Ćosić[1], Tomislav Maršić[1], Goran Krajačić[1], Natasa Markovska[2], Ilija Batas Bjelic[3], Dan-Ioan Gota[4], Zihnija Hasović[5], Nikola Rajaković[3] and Neven Duić[1]

1. University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia; email: boris.cosic@fsb.hr
2. Macedonian Academy of Sciences and Arts, Research Center for Energy, Informatics and Materials, Skopje, Macedonia
3. Department of Power Engineering, Faculty of Electrical Engineering, University of Belgrade, Serbia
4. EBS Romania, Cluj, Romania
5. EBRD TAM/BAS programme B&H, Sarajevo, Bosnia and Herzegovina

ABSTRACT

Regionally integrated energy systems can have significant benefits for countries which need extensive replacement and rehabilitations of the existing installations, have small energy markets and energy intensive economy. This paper examines benefits from integration of high share of intermittent renewable energy sources (RES) into energy system of the South East Europe (SEE). The energy system of the SEE is analysed on the basis of two scenarios in the EnergyPLAN model. First scenario is the “national scenario” which analyses benefits from RES integration into national energy systems of SEE countries. Second scenario is the “Integrated scenario” which analyses integration of intermittent renewable energy sources into regionally integrated energy system of the SEE. Total installed capacity of intermittent RES and its impact on the CO_2 emission reduction in both scenarios are determinate by taking into account economic limits for critical excess of electricity. The main findings are that total installed capacity of fluctuating RES and CO_2 emissions can be significantly increased in the SEE through integration of energy systems.

Keywords: South East Europe, Regionally integrated energy system, EnergyPLAN, CO_2 emission reduction

1 INTRODUCTION

The benefits from regionally integrated energy systems have countries with small energy markets and energy intensive economy [1]. The regional integration of energy systems, harmonisation of legislation and cross-border cooperation will lead to higher security of supply, lower electricity supply costs; reduced investment expenditures and to better economic efficiency [2] and [3].

The advantages of regional integrated energy systems and its impact on participating countries have been discussed in several articles. The advantages from development of the regional integrated power generation system instead of each country power generation system in the Western Africa has been analysed in [3] and results shows that through integration of power generation systems total generation costs can be lowered for 38 % compared to individual power generation system. The benefits of integration inter-regional electricity markets in East China has been analysed in [4] and results shows that inter-regional electricity market provide more energy generation capacities to the regional electricity utilities and market can benefit from optimal utilisation of resources and generation capacities. The benefits of regional energy co-operation for acceleration of the development process in sub-region of South Asia have been discussed in [5] while in [6] author analyse social cost-benefits of two electricity interconnector investment in Europe. The analysis conducted in [7] shows that one of the major reasons for regional co-operation is in the case when generation from renewable energy sources is increased. Furthermore, analysis conducted in [8] shows that flexibility of the system determines penetrations level of renewable energy sources and to reach goals stated in [9] for 2050 we need to have storage and balancing synergies. Also, recent analysis shows that wind penetration level and system flexibility are two main factors which have a highest influence on the operation of energy system [10].

This paper examines benefits from integration of a high share of intermittent renewable energy sources (RES) into energy system of the South East Europe (SEE). The energy system of the SEE is analysed on the basis of two scenarios in the EnergyPLAN model. First scenario is the "national scenario" which analyses benefits from RES integration into national energy systems of SEE countries. Second scenario is the "Integrated scenario" which analyses integration of intermittent renewable energy sources into regionally integrated energy system of the SEE.

2 METHODOLOGY

In order to conduct analysis of a high share integration of intermittent RES into the South East Europe Energy region, EnergyPLAN model [11] has been used (*Figure 1.*). The main purpose of the model is to assist the design of national energy planning strategies on the basis is an input/output model which incorporates heat and electricity supplies as well as the transport, individual and industrial sectors [13].

The EnergyPLAN model has already been used for the scenario analysis of energy systems with a high share of the intermittent sources. The model has been used for analysis of energy systems with a high share of combined heat and power (CHP) and wind power [14], large scale integration of fluctuating renewable energy sources into the electricity system [15], as well as in the analysis of 100% renewable energy systems of Croatia [16], Macedonia [17], Denmark [18] and Ireland [19]. Typical input data are demands, renewable energy sources, generation unit's capacities, storage capacities, fuel consumptions in individual, transport and industry sector, fuel costs, investment, variable and fixed operation and maintenance costs of different units, CO_2 emissions factors of fuels and different regulation strategies. The output data are annual, monthly and hourly values of electricity production, electricity import/export, import expenditures and export revenues, fuel consumption, CO_2 emissions and the share of

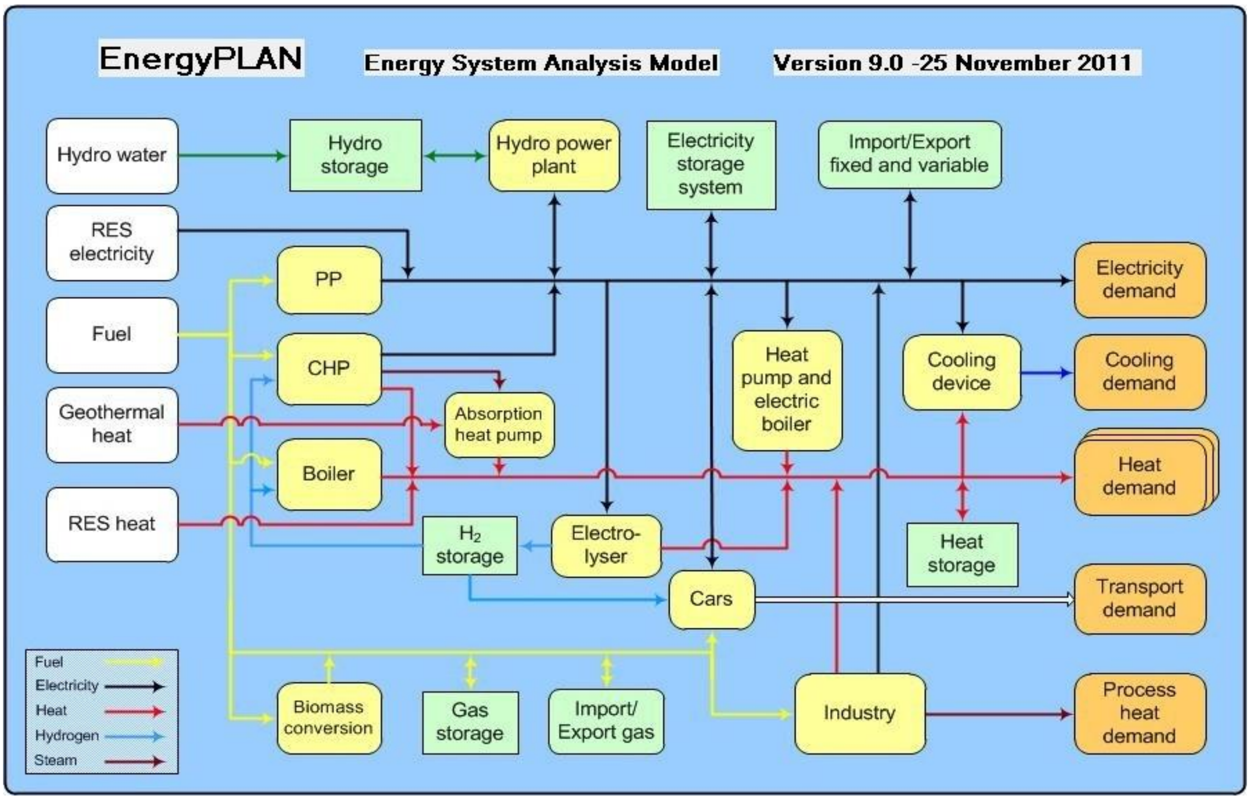

Figure 1. EnergyPLAN model

of technical and economic analyses of the consequences of different national energy systems and investments [12]. The EnergyPLAN RES. The model for analysis requires demand time series for electricity, district heating, individual heating, cooling and transport as well as distribution curve with an hourly resolution for wind, hydro, solar thermal, photo voltaic, geothermal and nuclear.

The model has four technical regulation strategies, and one electricity market strategy. The most commonly used strategies for the analysis are listed below:

1. Technical regulation strategy - balancing heat demands. CHPs produce only according to the heat demands
2. Technical regulation strategy - balancing both heat and electricity demand. CHP plants operate according to electricity and heat demand
3. Electricity market strategy. Plant optimisation based on business economic marginal production costs

Technical regulation strategy - balancing both heat and electricity demands, has been used in the analysis of the South East Europe energy system. In this strategy, large heat pumps in combination with CHP units are used to minimise export of electricity. Decrease in electricity production from CHP units lead to decrease in heat production which is balanced by increase in the heat produced by the large heat pumps at the CHP plants. Also, during the summer period, when the heat demand is very low and electricity load high, large CHP plants are working as condensing plants.

3 CASE STUDY: THE SOUTH EAST EUROP REGION

3.1 National reference energy systems

In order to investigate influence of a high share of renewable energy sources on energy system of the countries in SEE region, reference energy system of the SEE countries and integrated energy system of the SEE region have been created for the year 2008 in the EnergyPLAN model. Energy consumption and supply data for SEE countries have been taken from [20] while hourly wind power production was calculated by making use of hourly wind speed provided by METEONORM program [21] for the year 2008. Hourly production data for hydro power plants and hourly load data for the

Table 1. Installed generation capacities in the SEE region

Country	Year	Ref.	Hydro [MW]	Thermal [MW]	Nuclear [MW]	Biomass [MW]	Wind [MW]	PV [MW]	Other RES [MW]
Albania	2008	[23], [24]	1517	98	0	0	0	0	0
	2020	[25]	2091	938	0	230	1277	0	0
B&H	2008	[26], [27]	2031	1506	0	0	0	0	0
	2020	[28], [29]	3631	2251	0	50	700	100	0
Bulgaria	2008	[26], [30], [31]	2915	6827	2000	681	104	0	0
	2020	[32]	3288	8085	2000	839	1440	303	0
Croatia	2008	[26], [24]	1985	2090	0	0	17	0	0
	2020	[24], [33]	2486	2426	0	85	1201	42	90
Greece	2008	[30], [34]	3180	9496	0	0	1020	10	0
	2020	[35], [36]	6111	11578	0	560	7500	2450	120
Macedonia	2008	[37], [38]	581	800	0	0	0	0	0
	2020	[38]	1311	1214	0	5	400	50	0
Montenegro	2008	[26], [39]	650	191	0	0	0	0	0
	2020	[32], [40]	1311	411	0	15	200	0	0
Romania	2008	[24], [30]	6362	13730	1300	15	8	0	0
	2020	[35], [36]	7729	16285	1300	600	4000	600	0
Serbia	2008	[26], [24]	2835	4289	0	0	0	0	0
	2020	[24], [32]	4607	4890	0	50	500	100	0
Slovenia	2008	[30]	1027	1388	666	0	0	0	0
	2020	[35]	1353	1857	666	95	106	139	0
Kosovo*	2008	[26], [41]	43	1016	0	0	0	0	0
	2020	[26]	396	1621	0	10	150	50	0
TOTAL	**2008**		**23125**	**41431**	**3966**	**696**	**1149**	**10**	**0**
	2020		**34312**	**51555**	**3966**	**2539**	**17474**	**3834**	**210**

SEE countries have been obtained from UCTE for the year 2008 [22]. Load curves for hourly district heating demand have been calculated by using degree-day and temperature obtained from [21].

Installed generation capacity in the SEE countries have been obtained from different available publication and installed generation capacities in each country for the year 2008 and 2020 have been presented in *Table 1*. In the case of the SEE region, total electricity generation in 2008 was 277.4 TWh [20] and total generation capacity was around 70 GW. Installed capacity of coal fired thermal power plants was 27.1 GW, oil fired 3 GW and installed capacity of natural gas fired power plants was 11.2 GW. In the case of hydro power plants, total installed capacity was 23.1 GW of which 13.7 GW in storage hydro and 3.4 GW in pump hydro storage power plants. Installed capacity of nuclear power plants in Bulgaria, Romania and Slovenia was 4 GW. In the case of renewable energy sources, countries in the SEE region have installed very small capacities. Total installed capacity of biomass fired power plants was 695 MW, wind power plants 1150 MW and total installed capacity of Photo Voltaic was around 10 MW.

The CO_2 content of 74 kg/GJ for fuel oil, diesel and petrol, 56.7 kg/GJ for natural gas and 101.2 kg/GJ for coal have been used in the analyses [17].

3.2 The SEE scenarios and optimisation criteria

In order to investigate how will behave energy systems of the SEE countries and SEE region with a high share of the RES two scenarios have been proposed. First scenario is the "national scenario" which analyses benefits from RES integration into national energy systems of SEE countries. In this scenario minimum of the power plant is set at 50% of total installed generation capacities of thermal power plant.

Second scenario is the "Integrated scenario" which analyses integration of intermittent renewable energy sources into regionally integrated energy system of the SEE. In this scenario minimum of the power plant is set at the 50% of the operating capacity of the thermal power plant in the SEE. Operating capacity of the SEE is determined after deducting overhaul capacities of the power plants from total installed generation capacities. In the case of the SEE region this overhaul capacity is set to 12 % of the total installed generation capacities of thermal power plant.

Furthermore, in this study two different optimisation criteria for the maximisation of the penetration of RES in the energy system of the SEE have been used. In first case, critical excess of electricity (CEEP) is kept under 5 % (*optimisation criteria 1*), while in the second case, CEEP is kept under 10 % (*optimisation criteria 2*) of the wind production. CEEP is the amount of excess electricity produced that could not be used in the energy system. This excess is a result of the mismatch between supply and demand, and the inability of the energy system to absorb the extra electricity.

4 REULTS AND DISCUSSION

The analyses in the EnergyPLAN model is conducted for the closed energy system, which means that the total demand for electricity and heat is covered by own production. Furthermore, it is assumed that at least 30% of the power at any hour must come from power units capable of supplying ancillary (central power plant, CHP and hydro power plant). Under these assumptions, analyses were conducted for scenarios from section 3.2 and high share of wind electricity. The total generated electricity from wind power plants is varied from 0 % to 60 % of the total electricity demand of the SEE countries. Result of analyses for countries and the SEE region are presented on *Figure 2.*

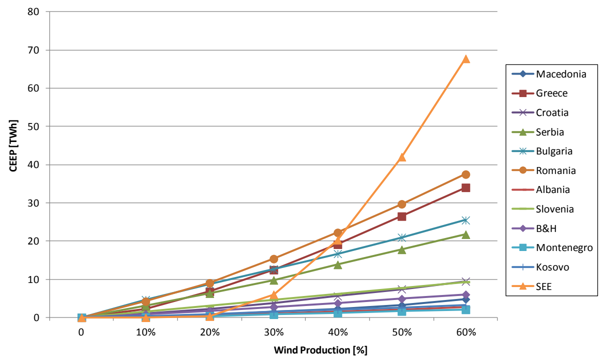

Figure 2. Excess electricity diagram for the SEE countries and integrated SEE region

According to the results presented in Figure 1, countries which have high installed capacities of coal power plants (Serbia and Greece) as well as nuclear power plants (Romania and Bulgaria) can integrate lower amount of wind electricity in the energy system without occurrence of the CEEP. Furthermore, analysis shows that integration of the SEE countries into single

energy system can significantly increase amount of the accepted wind electricity into system.
The results from the analysis conducted for the SEE countries with the optimisation criteria described above are presented in Figure 3.

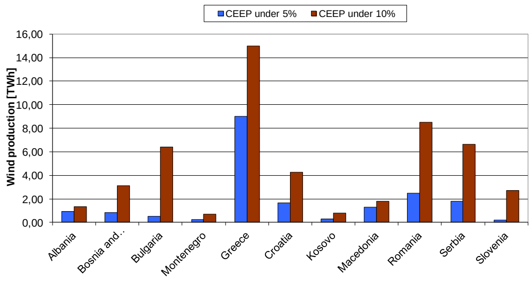

Figure 3. Maximum wind production in the SEE countries for different optimisation criteria

In the case of the integrated scenario results for the SEE region are presented in Figure 4. Furthermore, total production of wind electricity from national scenario is also presented on Figure 4.

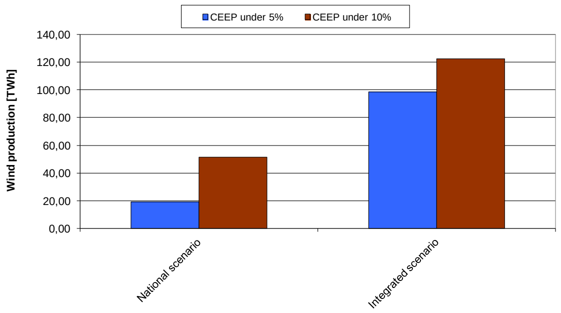

Figure 4. Maximum wind production for two SEE scenarios and different optimisation criteria

Results presented on Figure 4 shows that *integrated scenario* have higher potential for the wind integration. According to Figure 4, total wind production in the case of the optimisation criteria CEEP under 5 % is five time higher in the *Integrated scenario* then in *National scenario*. Total wind production in the national scenario is 19.22 TWh while in the case of integrated scenario total wind production is 98.65 TWh. In the National scenario highest wind production have Greece with 9 TWh followed by Romania with 2.47 TWh. The smallest capacity for the wind integration have Slovenia with 0.2 TWh followed by Montenegro with 0.26 TWh.
Results obtained for CO_2 emissions reduction in different scenarios by using optimisation criteria are presented in Fig. 5. Results shows that both scenarios can significantly reduce CO_2 emissions and that in the case of *integrated scenario* reduced amount of the CO_2 emissions are higher then in the case of *national scenario*. The total CO_2 emissions in the referent scenario for the SEE countries is around 345 Mt which can be reduced by applying *optimisation criteria 1* in the *National scenario* to 305 Mt and in the case of *Integrated scenario* to 279 Mt.

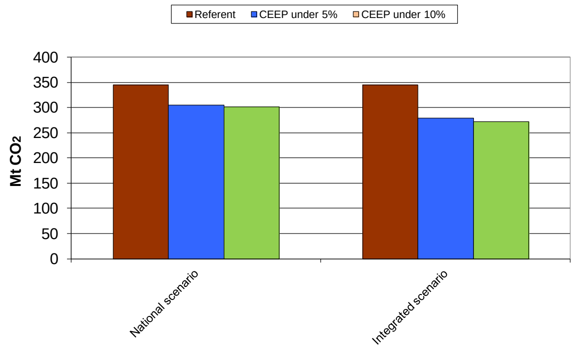

Figure 5. CO_2 emission for two scenarios and different optimisation criteria

In the case of the *optimisation criteria 2*, total CO_2 emissions in the *National scenario* are 301.5 Mt while in the case of *integrated scenario* CO_2 emissions are around 272 Mt.

5 CONCLUSION

Analysis conducted for two scenarios and different installed capacity of wind shows that the emissions of the CO_2 from the energy sector can be reduced between 11.5 % and 12.6 % in the case of *National scenario* and 19.1 % and 21.2 % in the case of *Integrated scenario*. Furthermore, analysis conducted for these two scenarios and *optimisation criteria 1*, shows that *Integrated scenario* can accept five times more wind electricity then *National scenario*. Through integration of energy systems of individual countries to a single market, efficiency of the energy system can be significantly increased which can resulted with cost reduction and higher RES penetration.
Finally, worth noting is that new storage technologies, such as electric vehicles and heat pumps together with investment in power plant flexibility, will further improve the penetration of renewables, decrease critical excess of electricity and save emissions. The follow-up research should deal with these technologies and quantify the effects of their introduction in the energy system. Also, future research should deal with socio-economic and business-economic aspects because this paper only investigates technical and environmental aspects of wind integration into various energy scenarios.

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